Minimizing Land Degradation and Sustaining Productivity by Integrated Watershed Management: Adarsha Watershed, Kothapally, India

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Abstract

Land degradation is a major threat for sustainable crop production in large areas of the semi-arid tropics (SAT). The Asian Development Bank gave financial assistance to evaluate the on-station watershed work of ICRISAT in on-farm situations. Adarsha watershed at Kothapally in Andhra Pradesh (AP), India is one of the benchmark sites where the evaluation was carried out. Instead of traditional structure driven approach, a new idea of integrated watershed approach was followed wherein various components of improved crop production were evaluated on a few selected individual farmers' fields in addition to community-based soil and water conservation activities. A new implementation arrangement called consortium approach wherein all the stakeholders, ICRISAT, DWMA, CRIDA, NGO, and farmers, planned and implemented various activities in a participatory manner was tried. This work has attracted not only the attention of AP Government but also many development agencies like DFID throughout the world. The AP Government is scaling-up this work in five districts through APRLP. It is one of the successful modules of watershed development. A grant by Sir Dorabji Tata Trust has been approved to replicate this work in Central and Northwest India. The success story of this work with details of various activities and the outputs is given in this paper.

Land degradation is a serious problem throughout the world, threatening economic and physical survival of mankind. Key issues on land degradation include escalating soil erosion, declining soil fertility, salinization, soil compaction, agrochemical pollution, and desertification. The result is a decline in the productive capacity of land. Existing estimates of the current global severity of the problem (Scherr and Yadav 1996) indicate that except for forest and woodland, the proportion of the land that is degraded is estimated to be more extensive in Africa and Asia. Oldeman (1994) assessed that globally, about 15% of the land is severely degraded. Water erosion was estimated at 56%, wind erosion at 28%, chemical degradation at 12%, and physical degradation at 4%. Asia's degradation is specifically attributed to deforestation with overgrazing and agricultural activities contributing as major factors. There is about 17% cumulative productivity loss between 1945 and 1990 as a result of land degradation (Crosson 1994). Lal (1995) estimated that the average yield reduction due to soil erosion is about 6%, ranging from 2 to 40%. The International Water Management Institute (IWMI) estimates show that 25% of the world's population and 33% of the developing country population live in regions that will experience severe water scarcity by 2025. One billion of the world's poorest people living in the semi-arid tropics (SAT) (Ryan and Spencer 2001) will be affected by water scarcity (Seckler et al. 1998). The poverty of Asia's poor is both a cause and a consequence of accelerating soil degradation and declining agricultural productivity. Poverty reduction is thus the major challenge for those responsible for policy and decision making on the protection and sustainable use of land resources in Asia.

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Poverty and Land Degradation

Whenever adverse changes occur in the world, it is usually the poor who suffer most. This situation arises from the very definition of the poor – those who lack adequate access to the basic necessities of life and the resources needed to obtain them. Because of land shortage, accentuated by degradation, the options for poor will be limited. Production will begin to fall and there will be an immediate attempt by the farmers in increasing the inputs to the crop and this non-sustainable management will lead to further degradation. So, it is poverty along with increased population that plays the greatest part in the casual nexus of land degradation and food insecurity in the developing world.

Erosion: On-site and Off-site Impacts

Erosion is the most important factor that degrades soils globally. It is a process where wind and water facilitate the movement of topsoil from one place to another. Soil erosion has been occurring for some 450 million years, but the problem has been accelerated more recently. As discussed above, this is a result of mankind's actions, such as over-grazing or unsuitable cultivation practices which make the land vulnerable during times of erosive rainfall or windstorms. Soil erosion occurs both incrementally, as a result of many small rainfall events, and more dramatically as a result of large but relatively rare storms. The most serious on-site impact due to erosion is decreased agricultural productivity as seen in several developing countries in Asia.

For sustainable management of natural resources such as water, soil, vegetation, and biota, watershed is a logical unit. Integrated watershed management approach covers wide-ranging aspects like health of the land (such as farming systems), agroforestry, infrastructure development, soil and water conservation, and community participation. Integrated watershed management is defined as an integration of technologies within the natural boundaries of a drainage area for optimum development of land, water, and plant resources to meet the basic needs of the people in a sustainable manner. Watershed management solutions must address the problem of rural poverty, protect the natural resources, and rehabilitate degraded areas, particularly those that pose hazards to human life and welfare. The approach improves the overall condition of land resources and also the living conditions of the people involved.

New Integrated Watershed Management Consortium Model

A new consortium model for efficient management of natural resources in the SAT has emerged from the lessons learned from long-term watershed-based research of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and national agricultural research system (NARS) partners (Wani et al. 2001). The important components of the new integrated watershed management model are:

- Farmer participatory approach through cooperation model and not through contractual model.
- Use of new science tools for management and monitoring of watersheds.
- Link on-station and on-farm watersheds.
- A holistic system's approach to improve livelihoods of people and not merely conservation of soil and water.
- A consortium of institutions for technical backstopping of the on-farm watersheds.
- A micro-watershed within the watershed where farmers conduct strategic research with technical guidance from the scientists.
- Minimize free supply of inputs for undertaking technology evaluation by the farmers.
- Low-cost soil and water conservation measures and structures.
- Amalgamation of traditional knowledge and new knowledge for efficient management of natural resources.
- Individual farmer-based conservation measures for increasing productivity of individual farms along with community-based soil and water conservation measures.
- Continuous monitoring and evaluation by the stakeholders.
- Empowerment of community individuals and strengthening of village institutions for managing natural watersheds.

About the Project

The project “Improving Management of Natural Resources for Sustainable Rainfed Agriculture” is funded by the Asian Development Bank (ADB) and was established in 1999 in an effort to improve the natural resource base and to have sustained increase in food production by SAT farmers. The present project involves watershed research in three countries (India, Thailand, and Vietnam), both on-station and on-farm. The Adarsha watershed at Kothapally in Ranga Reddy district of Andhra Pradesh is one of the three on-farm benchmark watersheds in India. The details of the project activities and results of the Adarsha watershed are described.

Process of Selection

ICRISAT and the District Water Management Aagency (DWMA) [earlier Drought Prone Area Programme (DPAP)], Government of Andhra Pradesh as well as M Venkatarangaiya Foundation (MVF), a non-governmental organization (NGO), together surveyed three watersheds in Andhra Pradesh and selected Adarsha watershed as one of the on-farm benchmark sites for the ADB-assisted project. In this watershed the total irrigable area was less and there was more dryland (80%). Not a single water harvesting structure for human and animal use existed at the time of survey in 1998, i.e., at the start of this project. A large area is under rainfed farming in the village. As there were no interventions made to conserve soil and water, this watershed was selected to encompass the concept of convergence in the watershed through consortium approach of managing and developing watersheds (Wani et al. 2001). Adarsha watershed was selected after a meeting of villagers in “Gram Sabha”, where the villagers came forward to participate in the proposed watershed activities. The objective was to improve rainfed agricultural production through integrated watershed development and reduce poverty of the farmers through increased systems productivity on sustainable basis while minimizing land degradation.

Consortium Partners

- ICRISAT
- Central Research Institute for Dryland Agriculture (CRIDA)
- DWMA, Government of Andhra Pradesh
- MVF
- National Remote Sensing Agency (NRSA)
- Farmers (Watershed Association, Watershed Committee, and self-help groups)

Developmental Actors

Different committees and groups were formed in the village and leaders were selected by the villagers themselves. The leaders were involved in the planning of watershed development activities from the initial stage (e.g., selection of the water harvesting sites), implementation of the activities, execution and assessment of all the developmental activities within the watershed. The various committees formed in the watershed are:

- Watershed Committee: The committee consists of a president, secretary, and 8 members representing different sections of the community.
- Watershed Association: The working committee consists of a chairman, a secretary, 8 committee members, and 270 members; i.e., farmers in the village.
- Women self-help groups – Vermicomposting: Ten groups were formed with 15 members each. These groups took up vermicomposting as an enterprise in the village.
- User groups: For water harvesting structures.
- Self-help groups: To undertake watershed development activities.

Approach

- Convergence of various activities in the watershed.
- No private contractors were involved in the watershed development activities.
- Inputs for technology evaluation were not free but were supplied at a minimum subsidy.
- Farmers conducted on-farm trials with technical support from ICRISAT and other research institutes in the consortium.
- Empowerment of farmers was through training and workshops.
- Availability of inputs and necessary machinery was ensured.
- The NGO’s strength for social mobilization was harnessed.

- Monetary disbursements were by watershed committees and not through the NGO/project implementing agency.
- Social auditing was done by the villagers.

The Initial Situation – Baseline Survey

At the outset of the project, a baseline data survey was carried out, which provided the necessary information on the existing resource-base and conditions of the village for monitoring and evaluation later.

Location

Adarsha watershed is located at longitude 78°5’ to 78°8’ E and latitude 17°21’ to 17°24’ N falling in Survey of India toposheet No. 56 K13 in the village of Kothapally, Shankarpally Mandal in Ranga Reddy district of Andhra Pradesh (Fig. 1). The total area of the watershed is 465 ha of which 430 ha is cultivated land.

Physiography

Vegetation

Main rainy season crops grown are sorghum, maize, cotton, sunflower, mung bean, and pigeonpea. In the postrainy season sorghum, sunflower, vegetables, and chickpea are grown. Wheat and rice are also cultivated.

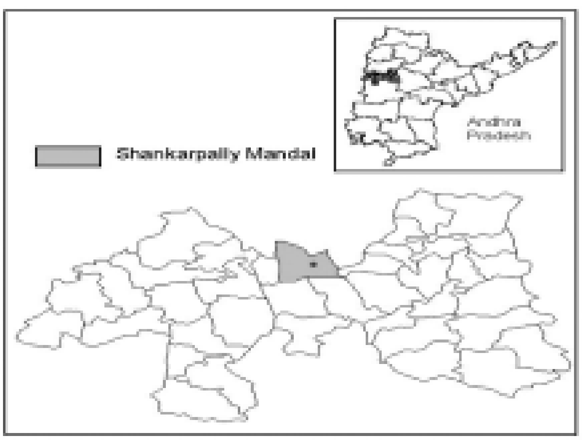

Figure 1. Location of Kothapally village in Shankarpally Mandal, Ranga Reddy district, Andhra Pradesh, India.

Climate

The annual rainfall in Kothapally is about 800 mm received mainly during June to October (85%). About 25–30% of the rainfall is lost as runoff carrying away the fertile topsoil.

Soils

The landscape of the watershed is made up of Vertisols and associated Vertic soils (90% of the area); Alfisols (10% of the area) are also present. Soil depth as perceived by the farmers and verified by the scientists through random samplings in the watershed is about 30–90 cm.

Social structure

The village consists of 274 households with the mean family size being seven. The total population is 1492, of which 54% belongs to backward communities, 15% to minorities, 20% to scheduled castes, and 9% to other castes. Beteille (1974) states that literacy and education may be unevenly distributed in an agrarian society and the data in Kothapally supports this statement with regard to inequalities between sexes and between castes. In Adarsha watershed, 40% of the land belongs to small holding farmers (0.01 to 1.00 ha), 40% to medium holding farmers (1.00 to 2.00 ha), and about 20% of the area to large holding farmers (>2.00 ha).

Groundwater table

The average depth of the 56 wells surveyed was 7.35 m (range 2–18.65 m). The variation in the groundwater table level and the amount of water harvested is based on the cropping patterns and other factors such as soil type, crops grown, topography, runoff, and geological factors of the area.

Crop productivities

The productivity of rice ranged between 0.27 and 2.4 t ha^{-1} for small landholders while for large landholders it was much less and varied from 0.19 to 0.9 t ha^{-1}. The average productivity in small, medium, and large landholdings was 1.1, 1.2, and 0.6 t ha^{-1} respectively. The same trend was observed for pulses also. The crop

Table 1. Crop productivities (t ha^{-1}) in Adarsha watershed, Kothapally in 1998.

Land-holders	Rice	Turmeric	Sorghum	Pigeonpea	Black gram	Cotton	Beans	Tomato	Other crops
Small	2.83	2.10	1.47	0.19	0.83	0.21	0.79	–	0.33
Medium	3.09	2.75	1.19	0.15	0.57	1.43	1.37	0.81	0.74
Large	1.66	1.23	0.54	0.13	0.25	0.67	0.19	0.75	1.33

productivities of cotton were 0.9, 0.6, and 0.3 t ha^{-1} for small, medium, and large landholders (Table 1).

Landholding size and use of inputs

Diammonium phosphate and urea

The majority of farmers use fertilizers. The amount of diammonium phosphate (DAP) and urea used declines sharply as land size increases.

Potash and super phosphate

These fertilizers are only applied to paddy by farmers in Kothapally. The amount of potash and super phosphate applied declines with increasing land size. In Kothapally watershed in general there is a rapid decline in usage of fertilizer with increase in landholdings of around 1–2 ha. As land size increases in Adarsha watershed the amount of fertilizer applied decreases.

Farmyard manure and compost

In the Adarsha watershed, the amount of farmyard manure (FYM) applied per hectare differs among the small landholdings. The most significant anomaly is that for a plot of 5 ha, nearly 6 t ha^{-1} of FYM is applied, and for a plot of about 4 ha approximately 1.5 t ha^{-1} of FYM is applied.

Weedicide and insecticide

Weedicide and insecticide are applied in various doses. The micro-watershed shows a sharp decline in weedicide and pesticide usage by farmers owning up to 0.4 ha, and a gradual decline with increasing land size.

Constraints

After the baseline survey, it was concluded that Kothapally village is characterized by various constraints such as:

- Low level of literacy
- Less proportion of irrigated area (20%) and higher dryland area (80%)
- Inverse relationship between land size and productivity
- Diversity in cropping systems between rainy and postrainy seasons
- Scarcity of labor
- Low crop productivity
- No water harvesting/storage structures
- Less use of fertilizers
- Low adoption of pest management practices
- Income generating activities are not taken up by women/villagers

Detailed characterization of soil samples

Soils of Kothapally watershed are of 4 series with varying depths of 0–40, 0–70, 0–90, and 0–120 cm. The soil series of 0–40 and 0–70 cm depth are developed on basaltic parent material having 1–3% gentle slope. These soils are shallow, well drained with moderate erosion. These soils have very dark grayish brown surface; subsurface horizons are clayey throughout the profile. These soils are suitable for growing sorghum, soybean, and black gram. Soil series of 0–90 and 0–120 cm depth are deep, moderately well drained, flat lands with gentle slope (0–1%). These soils have very dark brown surface horizon and very dark grayish brown to dark yellowish brown subsurface horizons which are clayey throughout the profile. The soils are developed from alluvium parent material suitable for long-duration crops like cotton, pigeonpea, turmeric, etc.

Soil samples from the watershed to a depth of 1 m are characterized in terms of their physical, chemical, and biological parameters. Surface soil pH in both medium and shallow soils was around 8.3. Soil pH increased with soil depth. The organic carbon (C) and total nitrogen (N) were more in medium-deep soils than in shallow soils. The organic C content of soils decreased from 5.7 g kg^{-1} to 1.0 g kg^{-1} in shallow soils and from 6.3 g kg^{-1} to 3.4 g kg^{-1} in medium deep soils in top 15 cm layer compared to 60–90 cm soil depth (Table 2). Similar trends were also observed for total N content. Available phosphorus (P) as estimated by Olsen's method was very low (1.4 to 2.2 mg kg^{-1} soil) in top 15 cm layer and decreased with increasing soil depth. The micronutrients like zinc (Zn), boron (B), and sulfur (S) were found to be lower than their critical limits. Fine sand and coarse sand were more in shallow soils while silt and clay were more in medium-deep soils (Table 3). Soil moisture content at wilting point varied from 21 to 27%.

Soil biological activity parameters such as microbial biomass, soil respiration, dehydrogenase, alkaline and acid-phosphatase activities are the direct measures that indicate the soil health. These biological properties are directly associated with transformations of various elements in soil which are needed for plant growth. Soil biological parameters varied significantly for shallow and medium-deep soils in the watershed. Like organic C and total N contents from microbial biomass C and N soil respiration and other biological

Table 2. Analysis of pre-sowing soil samples collected from Adarsha watershed, Kothapally, May 1999.

Properties	Land depth	0–15[1]	15–30	30–60	60–90	Mean	SE±
pH	Shallow	8.34	8.46	8.76	8.86	8.61	
	Medium	8.27	8.30	8.34	8.40	8.33	
	SE ±			0.04			0.034
	Mean	8.30	8.38	8.55	8.63		
	SE ±			0.02			
EC ($m\ mhos\ cm^{-1}$)	Shallow	0.20	0.17	0.23	0.40	0.25	
	Medium	0.19	0.17	0.17	0.16	0.17	
	SE ±			0.011			0.008
	Mean	0.19	0.17	0.20	0.28		
	SE ±			0.007			
Olsen-P (mg kg^{-1} soil)	Shallow	1.44	0.67	0.53	0.10	0.68	
	Medium	2.20	1.05	0.43	0.31	1.00	
	SE ±			0.245			0.182
	Mean	1.82	0.86	0.48	0.20		
	SE ±			1.34			
Organic C (g kg^{-1} soil)	Shallow	5.7	3.7	1.0	1.0	2.9	
	Medium	6.3	6.1	4.9	3.4	5.2	
	SE ±			0.60			0.52
	Mean	6.0	4.9	2.9	2.2		
	SE ±			0.24			
Total N (mg kg^{-1} soil)	Shallow	639	445	193	172	362	
	Medium	647	606	483	315	513	
	SE±			49.1			43.5
	Mean	643	526	338	244		
	SE±			18.6			

1. Soil depth (cm).

Table 3. Texture analysis of pre-sowing soil samples collected from Adarsha watershed, Kothapally, May 1999.

Properties	Land depth	0–15[1]	15–30	30–60	60–90	Mean	SE±
Coarse sand (%)	Shallow	13.9	22.9	41.1	43.7	30.4	
	Medium	7.6	7.8	10.4	25.9	12.9	
	SE ±			3.98			2.75
	Mean	10.7	15.3	25.7	34.8		
	SE ±			2.35			
Fine sand (%)	Shallow	9.4	13.3	15.6	16.2	13.6	
	Medium	5.7	5.8	6.9	11.4	7.4	
	SE ±			2.05			1.37
	Mean	7.6	9.6	11.2	13.8		
	SE ±			1.24			
Silt (%)	Shallow	21.5	17.3	18.1	19.2	19.0	
	Medium	25.0	22.3	20.4	16.7	21.1	
	SE ±			1.50			1.03
	Mean	23.3	19.8	19.2	17.9		
	SE ±			0.89			
Clay (%)	Shallow	55.2	41.3	31.6	24.7	40.7	
	Medium	61.7	64.4	62.3	48.2	59.2	
	SE ±			5.46			3.74
	Mean	58.4	52.9	46.9	41.5		
	SE ±			3.25			

1. Soil depth (cm).

parameters decreased with increasing soil depth in the profile (Table 4).

On-farm Trials and Farmers' Participation

Several farmers in the watershed are coming forward to take up on-farm trials in their fields with technical backstopping from ICRISAT. The number of farmers participating in these trials increased since start of the project. Overall, 137 and 138 farmer participatory trials were conducted in 2000 and 2001 respectively to evaluate improved management options. The area under on-farm trials in 2001 season was substantially increased to 108 ha as compared to that of 2000 (81.9 ha) and 1999 (36.8 ha) seasons.

Soil and Water Conservation Activities

An urgent need to conserve water and soil in the watershed is felt after a thorough analysis of the transect walk conducted. To control erosion and restore productivity of degraded soils in this area, several soil and water conservation activities were taken up to conserve the harvested water and increase the productivity of the crops. These activities are important in maintaining, improving, and enhancing productivity of the crops. Widespread adoption of improved practices is essential for controlling desertification and restoration of degraded soils. Engineering techniques of erosion control and runoff management can be made more effective when used in conjunction with biological control measures such as vegetative barriers, grassed waterways, etc. In Adarsha watershed in Kothapally, several soil and water conservation activities along with biological control measures were taken up both at farm and at community levels.

Ex-situ conservation

Excess water is drained away from the fields safely through grassed waterways. A total of 21 potential

Table 4. Soil biological properties of pre-sowing soil samples collected from Adarsha watershed, Kothapally, May 1999.

Properties	Land depth	0–15[1]	15–30	30–60	60–90	Mean	SE±
Soil respiration	Shallow	126	107	52	44	82	
(mg C kg^{-1} soil $10d^{-1}$)	Medium	157	112	96	75	110	
	SE ±			6.0			4.4
	Mean	142	110	74	59		
	SE ±			3.3			
Mineral N (NH_4+NO_3)	Shallow	10.3	7.1	5.8	4.2	6.8	
(mg N kg^{-1} soil)	Medium	11.7	10.1	5.7	4.9	8.1	
	SE ±			1.35			1.04
	Mean	11.0	8.6	5.8	4.5		
	SE±			0.71			
Net 'N' mineralization	Shallow	1.14	0.97	0.28	0.15	0.63	
(mg N kg^{-1} soil $10d^{-1}$)	Medium	2.05	1.12	1.08	0.57	1.21	
	SE ±			0.77			0.43
	Mean	1.59	1.04	0.68	0.36		
	SE ±			0.52			
Microbial biomass carbon	Shallow	288	214	123	62	172	
(mg C kg^{-1} soil)	Medium	267	191	160	109	182	
	SE ±			16.9			11.2
	Mean	278	203	141	85		
	SE ±			10.3			
Microbial biomass nitrogen	Shallow	45.5	33.9	19.5	9.8	27.2	
(mg N kg^{-1} soil)	Medium	42.3	30.2	25.2	17.2	28.8	
	SE ±			2.67			1.77
	Mean	43.9	32.0	22.4	13.5		
	SE ±			1.63			

1. Soil depth (cm).

sites for water storage structures were identified by the village committees and scientists' team and 10 structures were completed; 270 sites for gully control structures were identified and 70 structures were completed. Also, 40 ha for field bunding was proposed and completed and 10 gabion structures were proposed and one structure was completed.

In situ conservation

Shaping of the land reduces runoff. The land is made rough by broad-bed and furrow (BBF) landform treatment. The beds are prepared at 0.4 to 0.6% gradient. The BBF method helps to reduce runoff and conserves more water in the soil profile and also drains excess water safely away from the crops. This method is being adopted by the farmers in Adarsha watershed with technical backstopping from ICRISAT. Contour planting on flat (flat on grade) landform is also adopted by some farmers. Bullock-drawn tropicultor, developed by ICRISAT, is used by the farmers for planting, sowing, fertilizer application, and intercultivation. Planting of *Gliricidia* is done by farmers. About 30000 and 16000 *Gliricidia* plants were planted in 1999/2000 and 2000/01 respectively, on field bunds by the farmers for stabilizing the bunds to conserve the rainwater and soil. In addition these plants generate N-rich organic matter for field application for augmenting N supply for crop growth. This would reduce the dependence on mineral fertilizer N.

Wasteland development

Common wasteland treatment has been initiated in 1 ha land and contour trenches (10 m width and 0.3 m height) were laid out. Custard apple plantation was undertaken through local people on wastelands on the trenches during 2000 and 2001. In all 300 custard apple plants were planted. This will give additional income to the villagers as they can market the fruits in the adjacent cities. The wasteland boundaries were planted with *Gliricidia* plants at 0.5 m spacing to serve as live fence and also as a source of N-rich organic matter through loppings.

Avenue plantations

Avenue plantation was also taken up in the village as a part of the afforestation program in the village. Tree plantation along the roads, field bunds, and *nalas* was undertaken. Teak plantation (2500 trees) in private fields was also undertaken.

Integrated Nutrient Management

Vegetative bunds

In addition to grass planting, *Gliricidia* was planted on field bunds and used to conserve moisture and supply N to the crop through biologically fixed N by incorporation of loppings into the soil. This reduces the usage of fertilizers. During 1999–2001 farmers planted *Gliricidia* plants on their field bunds.

Nutrient budgeting and balanced fertilization trials

In the watershed, 15 farmers are following the improved soil, water, and nutrient (SWNM) management options along with conventional practices. Balanced nutrient doses were used for sustaining productivity in these watersheds. *Rhizobium* inoculation of pigeonpea and soybean seeds was done to increase biological nitrogen fixation (BNF). Crop responses were positive to specific nutrient amendments. Based on soil analysis, B and S applications were done at Kothapally and increased yields were observed. Higher grain yields were obtained with improved practices and this indicates a considerable scope for savings on N fertilizer. Quantification of BNF using N-difference method is being done using non-fixing crop (maize and sesame) varieties of matching duration with groundnut and soybean in farmers' fields.

The nutrient uptake by maize/pigeonpea intercrop system was more in the improved systems as compared to that of flat landform treatment. The N-difference and ^{15}N isotope dilution methods were used to quantify BNF contributions of legumes using non-fixing control plants. Similarly, for the sole maize crop uptake of nutrients was more in BBF system than the flat landform. The nutrient balances based on the available data sets showed that in this watershed all the systems are depleting potassium (K) from soils and more P is applied than removed by the crops. Nutrient removal was also more in BBF than in the flat landform treatment. Higher negative N balance in maize/pigeonpea in BBF system (–55 kg N ha^{-1}) shows that the crop extracted more N from the soil when grown on BBF system than on flat system (–48 kg N ha^{-1}) (Table 5).

In situ generation of organic matter for green manuring

Leguminous green manures such as *Gliricidia* are important in maintaining soil and crop productivity. Decomposition and nutrient release of *Gliricidia* loppings occur at a faster rate due to low C:N ratio. Most of the nutrients especially N and K are released within 5–10 days of decomposition. Decomposing leaf prunings of *Gliricidia* are better and rapid source of nutrients. Forty-six thousand *Gliricidia* plants were planted during 1999–2001 by farmers on their field bunds at Kothapally.

Vermicomposting Boosts Incomes

Earthworms are used in vermicomposting as they are voracious eaters and can transform organic wastes into compost in a short span. Compost which is processed by earthworms makes good organic fertilizer as it contains auxins, a growth promoter for plants and also some natural antibiotics along with plant nutrients. Vermicomposting is a cost-effective pollution abatement technology. At Kothapally, 52 women farmers were identified for vermicomposting units. Of

Table 5. Nutrient budgeting in farmers' fields in Adarsha watershed at Kothapally, 1999–2000.									
Cropping system/	Total inputs			Total outputs			Balance		
Landform	N	P	K	N	P	K	N	P	K
Maize/pigeonpea									
BBF	28.3	16.4	17.1	84.5	10.6	57.6	–55	+6	–40
Flat	32.2	13.8	21.2	80.2	8.8	49.7	–48	+5	–29
Sole maize									
BBF	20.5	10.0	0.0	74.8	14.1	70.6	–55	–4	–70
Flat	9.0	10.0	0.0	32.7	7.3	35.9	–24	+3	–35
Sole sorghum									
Flat	18.3	9.9	11.0	41.8	9.7	64.3	–24	+0.2	–53

the ten existing women groups, five groups were formed and trained in vermicomposting techniques. The groups started the units with the available organic wastes, cow dung, etc. These women self-help groups have taken up vermicomposting as a micro-enterprise to generate income.

Method of vermicomposting

Agricultural residues like sorghum straw, paddy straw, dry leaves, pigeonpea stalk, groundnut husk, wheat husk, weeds like *Parthenium,* and agricultural wastes (e.g., animal manures); dairy and poultry wastes; food industry wastes; municipal solid wastes; biogas-sludge; and bagasse from sugarcane industry can be used as raw material for vermicomposting. The composting is done in cement rings or 1.5 m^3 tanks. Dry organic wastes, dung slurry, rock phosphate, earthworms, and water are mixed (10:3:0.4:100–150:1). The bottom of the tank is filled up with dry material like coconut husk or a polythene sheet is spread and on this 15–20 cm of organic wastes is filled as a first layer, rock phosphate as the second layer, and dung slurry as third layer. More layers are filled one above the other in the tank. The top layer is plastered with mud slurry to prevent moisture loss. This is left to decompose for 15 days to dissipate the heat generated during initial decomposition. Earthworms are released into the compost through the cracks after 15 days. To maintain adequate moisture, water should be sprinkled on the vermicompost tank intermittently. The compost will be ready within 6–8 weeks. The vermicompost is heaped in a cone shape. The earthworms move to the bottom out of the compost heap and these can be collected and used again.

Response of tomato to vermicompost application

In 2001, a demonstration plot was initiated in the village with a plot size of 300 m^2. Vermicompost was applied to the standing crop of tomato at 3–5 t ha^{-1}. The productivity (5.8 and 4.8 t ha^{-1}) of tomatoes was significantly higher in plots with 3 and 5 t ha^{-1} vermicompost when compared with plots with conventional compost (3.5 t ha^{-1} yield). The worm castings in the vermicompost have nutrients that are 97% utilizable to the plants.

Integrated Pest Management

Integrated pest management (IPM) is the coordinated use of pest and environmental information to design and implement pest control measures that are economically, environmentally, and socially sound. It promotes prevention over remediation and advocates integration of at least two or more strategies to achieve long-term solutions. IPM uses methods such as crop or site scoring, pest trapping, pest tolerance crop varieties, weather monitoring, cultural controls, biological controls, and precise timing and application of pesticide treatments, only when needed. Complete dependency on chemical control for the past three decades led to unsatisfactory pest management along with environmental degradation. ICRISAT along with national agricultural research and extension systems

(NARES), NGOs, and farmers conducted research in the watershed to identify environmentally sound and economically viable plant protection technologies which reduce yield losses and improve farmers' income. Farm surveys and participatory rural appraisals identified the non-availability of IPM components such as plant-based products, nuclear polyhedrosis virus (NPV), pheromones, and pest tolerant varieties. The farmers harvested six-fold increased yields through better management of pests by controlling them with neem seed extract. There was 6–100% reduction in pesticide usage. After thorough evaluation of the existing pest management options, a comprehensive IPM package for chickpea and pigeonpea was developed and evaluated in farmer participatory approach mode. Revitalizing the effective indigenous methods like shaking of pod borers from the pigeonpea crop and use of neem for pest management was done in both the watersheds. These indigenous methods are effective, cheaper, and environment-friendly. Installation of pheromone traps for pest monitoring was done every year. Bird perches were also installed in the fields for birds to rest and feed on the *Spodoptera* larvae.

Crop surveys

Crop surveys were carried out to know the plant protection practices followed by farmers in Kothapally. All the farmers interviewed indicated use of chemical pesticides against insect pests. They indicated *Helicoverpa* as the key pest on several crops. Endosulfan, cypermethrin, fenvalerate, monocrotophos, and quinalpos were the commonly used chemicals across the farming community. Precautions were not taken while spraying. This preliminary survey clearly brought about several inappropriate ways of chemical usage, which need to be addressed in the coming years.

Pest control

Cotton

Cotton crop was sown in the first fortnight of June with the onset of monsoon. Initially farmers could protect their crop by 3–4 chemical sprays against sucking pests like jassids, aphids, and whiteflies. *Helicoverpa* population was controlled by *Helicoverpa* NPV (HNPV), which kept the population below the economic injury level.

Pigeonpea

Pigeonpea crop was sown as both sole and intercrop with maize or sorghum. *Helicoverpa* was the key constraint to pigeonpea production. The adult population of *Helicoverpa* was monitored using pheromone traps. The farmers applied neem sprays and HNPV sprays followed by manual shaking. No chemical sprays were used. These farms had lower pod borer damage and higher yields when compared with fields where IPM practices were not followed.

Chickpea

Observations of egg and larval populations indicated the onset of pest infestation, particularly *Helicoverpa* and farmers applied HNPV in their fields. The farmers obtained three-fold more yield (780 kg ha^{-1}) than yields obtained by farmers (250 kg ha^{-1}) who did not adopt IPM in their fields. The increased yields are due to IPM as well as the use of the variety ICCV 37 supplied by ICRISAT.

Monitoring *Helicoverpa* by pheromone traps

Population of adult *Helicoverpa* was monitored in Kothapally village from 2000 by using pheromone traps with the pheromone lures obtained from the Natural Resources Institute (NRI), UK.

Village-level HNPV production

Among various options, the availability of good quality HNPV was considered a prime component for spread of IPM. This project quickly identified and initiated village-level production to cater to the needs of farmers. Many farmers and extension workers from this village were given training on HNPV production, storage, and usage on different crops. The villagers quickly adopted the technology and produced 2000 larval equivalents (LE) of virus and used on cotton, pigeonpea, and chickpea crops. Besides the village-level production, 11650 LE HNPV was supplied to the farmers through ICRISAT to cover cotton, pigeonpea, and chickpea crops.

The project has given high priority for training village scouts in identifying various pests and their natural enemies in different crops before the cropping season, and assisted them in monitoring throughout the crop period. A slide show emphasizing cropping systems, various pests and diseases and their management was organized for the whole village including children. Video shows on correct use of plant protection emphasizing the importance of IPM were displayed in the village twice during the season. Farmers were trained on HNPV production at ICRISAT, Patancheru and were assisted to take up village-level HNPV production. Extension handouts on packages of practices for chickpea and pigeonpea crops in local language were distributed.

Future of IPM at Kothapally

In the coming years, ICRISAT will be involved in development of technologies for high quality insect pathogens to strengthen the existing IPM activities (viral and fungal pathogens). Basic research needs to be conducted on the insect host plant interaction and cultural operations on pests and on natural enemies. Potential plant products that are safe and effective in pest management should be identified and developed. Insecticidal resistance in both pests as well as natural enemies should be monitored. Village-based or regional-based IPM approach should be developed rather than pest-wise or crop-wise approach. Training clients (researchers, extension workers, NGOs, and farmers) at all levels in IPM concepts is needed.

Monitoring

To evaluate the impact of watershed management continuous monitoring of all the parameters is done. An automatic weather station was installed to continuously monitor the weather parameters (Figs. 2 and 3; Table 6). To monitor the groundwater levels 64 open wells in the watershed were geo-referenced and regular monitoring of water level and quality was done (Fig. 4). Runoff, and soil and nutrient losses are monitored using automatic water level recorders and sediment samplers (Fig. 5; Table 7).

Quantification of BNF in farmers' fields was carried out using N difference method and ^{15}N isotope dilution method. Pheromone traps were installed to monitor *Helicoverpa* populations. Changes in cropping intensity, greenery, water bodies, and groundwater levels were monitored. Geographical information system (GIS) maps indicating soil types, soil depths, and crops grown during rainy and postrainy seasons have been prepared. Crop productivities were recorded for each crop every year.

Impact

Improved greenery

The normalized difference vegetation index (NDVI) has been used to monitor the impact of the

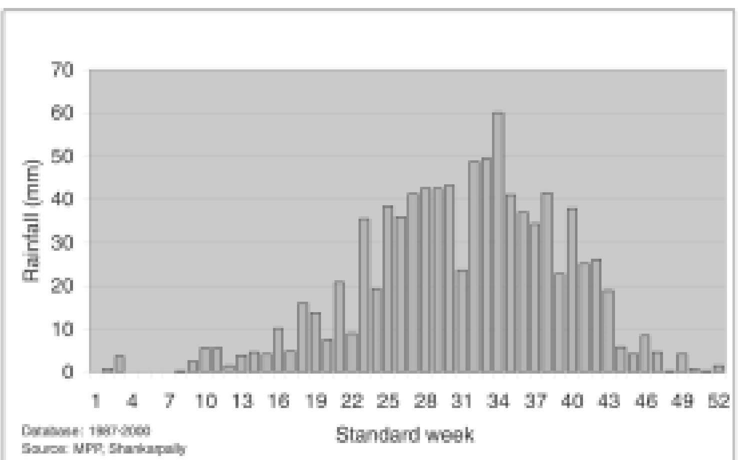

Figure 2. Average weekly rainfall recorded at Shankarpally Mandal, Andhra Pradesh.

Month	Rainfall (mm)	Max. temp. (°C)	Min. temp. (°C)	Solar radiation (MJ m^{-2})
1999				
6	54.50	32.49	22.02	16.81
7	139.24	30.56	20.99	17.36
8	150.59	29.06	20.46	15.84
9	115.05	29.11	20.36	14.64
10	50.90	30.49	18.34	15.81
11	0.00	29.59	12.57	17.08
12	0.00	28.07	9.54	15.56
2000				
4	4.09	41.56	23.60	22.83
5	138.00	37.99	23.54	22.25
6	165.30	31.75	22.26	15.15
7	132.29	29.96	21.71	15.08
8	460.09	30.26	21.88	14.04
9	103.69	32.14	20.86	18.03
10	12.40	34.35	19.78	17.55
2001				
1	12.70	32.62	15.08	16.09
2	1.30	30.99	14.84	12.64
3	4.80	39.09	20.50	20.29
4	27.70	39.24	22.48	20.22
5	12.20	41.15	25.85	22.37
6	112.29	33.89	22.60	17.20
7	19.60	31.97	22.65	14.86

Table 6. Monthly weather data recorded at Adarsha watershed, Kothapally, 1999–2001.

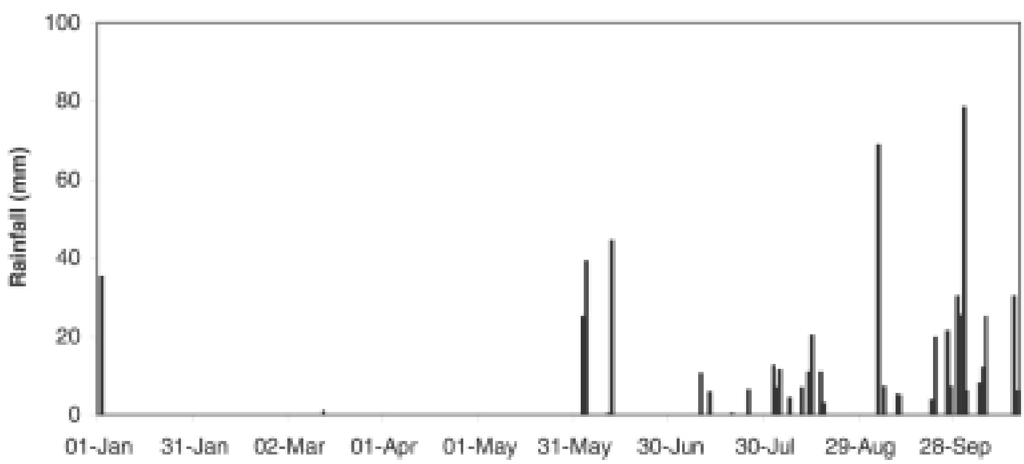

Figure 3. Rainfall recorded at Adarsha watershed, Kothapally, 2001.

Table 7. Annual rainfall, runoff, and peak runoff rate at Adarsha watershed, Kothapally, 2001.

Description	Treated watershed	Untreated watershed
Annual rainfall (mm)	612	612
Runoff (mm)	22	31
Peak runoff rate ($m^3 s^{-1} ha^{-1}$)	0.027	0.022

Figure 4. Location map showing open wells in Adarsha watershed, Kothapally.

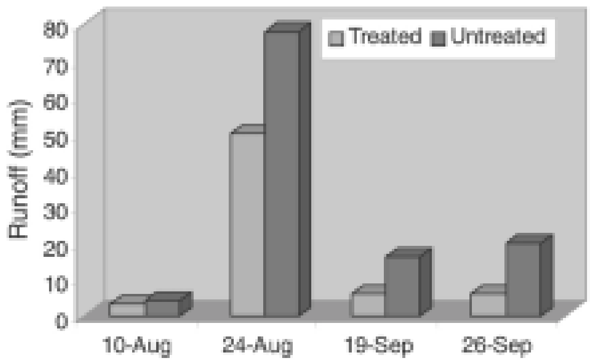

Figure 5. Runoff from two sub-watersheds at Kothapally, 2000.

implementation of action plan. An increase in the vegetation cover which reflects an improvement in the vegetation cover was observed. The spatial extent of moderately dense vegetation cover which was 129 ha in 1996 has increased to 152 ha by 2000.

Increased groundwater levels

The groundwater levels and other related observations (pumping hours, area irrigated from each well and distance between the well and check-dam) from watersheds were collected. At Kothapally watershed, throughout the season higher groundwater levels were recorded from the well near the major check-dam compared to water levels in wells away from the check-dam (Fig. 6). This clearly shows the effectiveness of the improved watershed technologies in increasing the groundwater recharge thereby improving the availability of water for agricultural and other uses.

Improved productivities and incomes for farmers

At Kothapally, farmers evaluated improved crop management practices along with improved land management practices such as sowing on BBF landform and flat sowing on contour; and using improved bullock-drawn tropicultor for sowing and interculture operations. Farmers obtained two-fold increase in the yields in 1999 (3.3 t ha^{-1}) and three-fold increase in 2000 (4.2 t ha^{-1}) as compared to the yields of sole maize (1.5 t ha^{-1}) in 1998 (Table 8). In intercropped maize with pigeonpea, improved practices gave a four-fold increase in maize yield (2.7 t ha^{-1}) compared with farmers' practices where the yields were 0.7 t ha^{-1}. In sole sorghum the improved practices adopted increased yields three-fold within one year. In 1999/2000, farmers achieved highest system productivity, total income, and profit from improved maize-pigeonpea and improved sorghum/

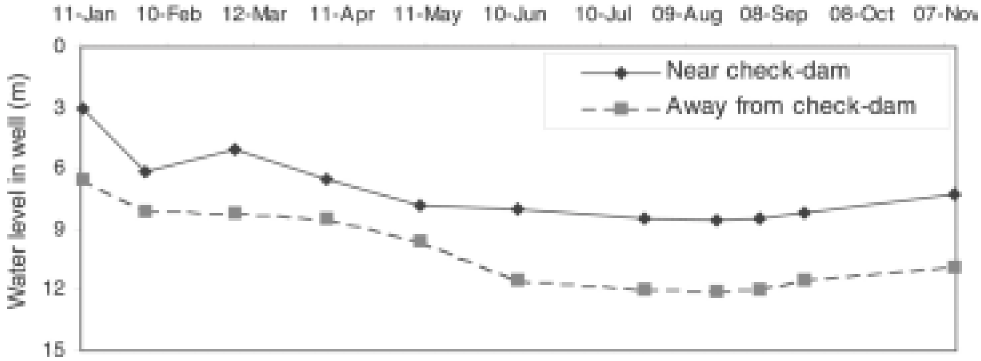

Figure 6. Effect of check-dam on groundwater recharge in Adarsha watershed, Kothapally during 2000.

Table 8. Average crop yield (kg ha^{-1}) with improved technologies in Adarsha watershed, Kothapally, 1999–2001.

Crop	1998 Baseline yield	1999	2000	2001
Sole maize	1500	3250	3750	3300
Intercropped maize	-	2700	2790	2800
(Farmers' practice)		700	1600	1600
Intercrop pigeonpea	190	640	940	-
(Farmers' practice)		200	180	-
Sole sorghum	1070	3050	3170	2600
Intercrop sorghum	-	1770	1940	2200

pigeonpea intercropping systems. Along with the highest system productivity the cost-benefit ratio of the improved systems was greater (1:2.47) compared to the farmers' traditional cotton-based systems (Wani 2000). In 2000/01, several farmers evaluated BBF and flat landform treatments for shallow and medium deep black soils using different crop combinations. Farmers harvested 250 kg more pigeonpea and 50 kg more maize per hectare using BBF on medium-deep soils than the flat landform treatment. Furthermore, even on flat landform treatment farmers harvested 3.6 t ha^{-1} maize and pigeonpea using improved management options compared to 1.72 t ha^{-1} maize and pigeonpea using normal cultivation practices.

Similar benefits from improved BBF landform and also improved management options were reported by the farmers in shallow soils and with other cropping systems. The rainfall during 1999 in this area was 559 mm, which is 30% below normal rainfall, and in 2000 the rainfall was 958 mm, which is 31% above normal. In spite of this variation in the rainfall received in 1999 and 2000, the productivity of the crops marked a sustainable increase during 1999/2000 and 2000/01.

Of all the cropping systems studied in Adarsha watershed, maize/chickpea and maize/pigeonpea proved to be more beneficial to farmers (Table 9). Farmers could gain about Rs 19590 and Rs 17802 with these systems respectively. Sorghum, chickpea, and pigeonpea sole cropping systems also proved beneficial, whereas sorghum, maize, and chickpea traditional systems were significantly less beneficial to the farmers.

Table 9. Benefit-cost ratio of different cropping systems at Adarsha watershed, Kothapally, 2001.

Cropping system	Total productivity (kg ha^{-1})	Total cost (Rs ha^{-1})	Total income (Rs ha^{-1})	Profit (Rs ha^{-1})	Benefit-cost ratio
Improved					
Maize/chickpea	4700	6883	26473	19590	1:2.85
Maize/pigeonpea	3753	6342	24144	17802	1:2.81
Maize	3000	4150	12260	8110	1:1.96
Sorghum	3000	3850	13860	10010	1:2.60
Chickpea	850	5250	18000	12750	1:2.43
Pigeonpea	1090	4890	17120	12230	1:2.50
Traditional					
Maize/chickpea	2750	5915	16650	10735	1:1.82
Maize/pigeonpea	1715	4452	12769	8317	1:1.87
Sorghum/pigeonpea	1116	4050	11610	7560	1:1.87
Cotton	1163	16990	26748	9758	1:0.57
Maize	1600	3360	7500	4140	1:1.23
Chickpea	-	4260	11600	7340	1:1.72
Sorghum	1011	3050	7055	4005	1:1.31

Human Resource Development

Farmers are exposed to new methods and technologies for managing natural resources through training and field visits to on-station and other on-farm watersheds. Farmers and landless families were trained and encouraged to undertake income generating activities in the watershed, which can help sustain the productivity at watershed level. Various training sessions were held for farmers on improved management options like providing training on farm implements, IPM, and integrated nutrient management options. Along with the farmers, watershed committee members and agriculture and extension officials were trained at ICRISAT on different aspects of integrated watershed management. Research scholars and apprentices from various universities of India, Thailand, Vietnam, and New Zealand conducted research on integrated watershed management. Special emphasis was laid to educate women farmers and increase awareness on new management options. More women were trained in vermicomposting technology at Kothapally. Educated youth were trained in skilled activities like NPV production and vermicomposting, which helped them in generating income (Table 10).

Technology Imbibing into Other Watersheds

Around ten watershed farmers from Nawabpet (Yellakonda watershed, Sainnaguda watershed, Lingampally watershed, Maitaphkanguda watershed, and Gullaguda watershed) and Adilabad adopted the improved practices which proved to be beneficial in Adarsha watershed, Kothapally and they are in the process of evolution. Farmers adopted BBF landform in their fields. Use of tropicultor for sowing, fertilizer application, and intercultivation activities impressed them very much and they bought tropicultors for their respective villages. Improved cropping systems like sorghum/pigeonpea, maize/pigeonpea, sole sorghum, chickpea and maize cropping systems were taken up in about 206 ha in these watersheds. Improved soil and water conservation measures have been initiated in these watersheds. Farmers are found to be keenly interested in adopting *Gliricidia* plantations, vermicomposting, and HNPV production in their respective villages.

Table 10 Various training programs conducted on integrated watershed management at Kothapally, 2000–01.

Stakeholders	Number of training courses	Participants
Farmers	5	675
Agricultural officials	3	80
Government officials/nodal officers	3	60
Non-governmental organization/ Project implementation agencies	1	30
Research scholars/Apprentices from various countries	-	14
Visitors	-	800

Why is Adarsha Watershed a Model Watershed?

The Adarsha watershed is said to be a model watershed as all the activities are through community initiatives and the strength lies in local participation of people, especially through women empowerment. The project improved the livelihoods of the poor by increasing the farm productivities, farm incomes, groundwater levels, and improving greenery. The capacity of local governments and community-based organizations has been enhanced through watershed management and decision-making processes. This project is aware of the need to involve local residents and community-based organizations, given that residents possess unique, first-hand knowledge about local resources and environmental threats.

Conclusion

On-farm trials were conducted by ICRISAT in 1980s and the results on station were replicated in farmers' fields. But even after 15 years in the same village, the improved practices were not adopted by the farmers of the village; they went back to their traditional practices. The researchers found the loopholes for low adoption of the technology package. A new model of integrated watershed management was developed by ICRISAT with the lessons learned on farm. Contractual mode of farmer participation did not achieve good results, so a higher degree of farmer participation through consultative and cooperative mode was initiated and found to be successful in the watershed. Gender issues were considered high priority. As women are the key players in development of the society, keen interest was taken to empower women in various income generating activities like vermicomposting and HNPV production within the village. On-farm trials were conducted in farmers' fields by providing them only with technical backstopping; no subsidies were given. Social auditing was done by the villagers themselves. To sustain the productivity in the SAT, a holistic approach of integrated watershed management still needs to be scaled up through appropriate policy and other institutional support and the on-site and off-site impacts need to be studied.

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